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# मानक

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भारतीय मानक

मानव शरीर में धारा के प्रवाहित होने के प्रभावों की मार्गदर्शिका

भाग 1 सामान्य पहलू

( पहला पुनरीक्षण )

*Indian Standard*

## GUIDE ON EFFECTS OF CURRENT PASSING THROUGH THE HUMAN BODY

**PART 1 GENERAL ASPECTS**

*( First Revision )*

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MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG  
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## NATIONAL FOREWORD

This Indian Standard ( Part 1 ) which is identical with IEC Pub 479-1 (1984) 'Effects of current passing through the human body Part 1 : General aspects', issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of the Electrical Installations Sectional Committee (ET 20) and approval of the Electrotechnical Division Council.

This guide provides the basis for fixing requirements for protection against electric shock . This standard was originally brought out in 1977 based on the then studies conducted world over. Since then, considerable experience has been gained the world over on effects of current of various types and under different conditions. In view of the universality of this study conducted under

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*Indian Standard*

# GUIDE ON EFFECTS OF CURRENT PASSING THROUGH THE HUMAN BODY

## PART 1 GENERAL ASPECTS

*( First Revision )*

### INTRODUCTION

In order to avoid errors in the interpretation of this report it must be emphasized that the data given herein are mainly based on experiments with animals as well as on information available from clinical observations. Only a few experiments with shock currents of short duration have been carried out on living human beings.

On the evidence available, mostly from animal research, the values are so conservative that the report applies to persons under normal physiological conditions, including children irrespective of age and weight.

This report is intended to provide basic guidance on the effects of shock currents on the human body for use in the establishment of electrical safety requirements.

There are, however, other aspects to be taken into account, such as probability of faults, probability of contact with live or faulty parts, ratio between touch voltage and fault voltage, experience gained, technical feasibilities and economics. These parameters have to be considered carefully when fixing safety requirements, for example operating characteristics of protective devices for electrical installations.

The form of report has been adopted, as it summarizes results so far achieved which are being used by Technical Committee No. 64 as a basis for fixing requirements for protection against shock. These results are considered important enough to justify an IEC publication, which may serve also as a guide to other IEC Committees and countries having need of such information.

The first edition of Publication 470 was issued in 1974 and was based on an extensive search in literature and on the evaluation of replies received to a questionnaire. However, since that date, new research work has been conducted on this subject. The study of this work and a more precise analysis of preceding publications have allowed a better understanding of the effects of electric current on living organisms and, in particular, on man.

This specifically applies to the limits of ventricular fibrillation which is the main cause of deaths by electric current, and the analysis of all results of recent research work on cardiac physiology and on the fibrillation threshold taken together, has made it possible to better appreciate the influence of the main physical parameters, and especially of the duration of the current flow.

Recent research work has also been conducted on the other physical accident parameters, especially the waveform and frequency of the current and the impedance of the human body. This revision of Publication 479 was therefore considered necessary and should be viewed as the logical development and evolution of the first edition.

## CHAPTER 1: ELECTRICAL IMPEDANCE OF THE HUMAN BODY

### 1. General

For a given current path through the human body, the danger to persons depends mainly on the magnitude and duration of the current flow. However, the time/current zones specified in the following chapters are, in many cases, not directly applicable in practice for designing protection against electric shock, the necessary criterion being the admissible limit of touch voltage (i.e., the product of the current through the body and the body impedance) as a function of time. The relationship between current and voltage is not linear because the impedance of the human body varies with the touch voltage, and data on this relationship is accordingly required.

The different parts of the human body—such as the skin, blood, muscles, other tissues and joints—present to the electric current a certain impedance composed of resistive and capacitive components.

The values of these impedances depend on a certain number of factors and, in particular, on the current path, on the touch voltage, the duration of the current flow, the frequency, the degree of moisture of the skin, the surface area of contact, the pressure exerted and on the temperature.

The impedance values indicated in this report result from a close examination of the experimental results available from measurements carried out principally on corpses and on some living persons.

### 2. Scope

This chapter indicates values for the electrical impedance of the human body as a function of the touch voltage, the frequency, the degree of moisture of the skin and the current path.

*Note.* — The values given in Clause 5 refer to frequencies of 50/60 Hz; values for higher frequencies and for direct current are under consideration.

### 3. Definitions

#### 3.1 *Internal impedance of the human body ( $Z_i$ )*

Impedance between two electrodes in contact with two parts of the human body, after removing the skin from under the electrodes.

#### 3.2 *Impedance of the skin ( $Z_p$ )*

Impedance between an electrode on the skin and the conductive tissues underneath.

#### 3.3 *Total impedance of the human body ( $Z_T$ )*

Vectorial sum of the internal impedance and the impedances of the skin (see Figure 1, page 5).

#### 3.4 *Initial resistance of the human body ( $R_i$ )*

Resistance limiting the peak value of the current at the moment when the touch voltage occurs.

#### 4. Characteristics of the impedance of the human body

A circuit diagram for the impedances of the human body is shown in Figure 1, page 5.

##### 4.1 Internal impedance of the human body ( $Z_i$ )

The internal impedance of the human body can be considered as mostly resistive. Its value depends principally on the current path and, to a lesser extent, on the surface area of the contact. However, when the surface area of contact is very small, in the order of a few square millimetres, the internal impedance is increased.

*Note.* — Measurements indicate that a small capacitive component exists (dashed lines in Figure 1).

Figure 2, page 5, shows the internal impedance of the human body for various current paths expressed as percentages of that related to the path hand to hand.

##### 4.2 Impedance of the skin ( $Z_p$ )

The impedance of the skin can be considered as a network of resistances and capacitances. Its structure is made up of a semi-insulating layer and small conductive elements (pores). The skin impedance falls when the current is increased. Sometimes current marks are observed.

The value of the impedance of the skin depends on the voltage, frequency, duration of the current flow, surface area of contact, pressure of contact, the degree of moisture of the skin and temperature.

For touch voltages up to approximately 50 V, the value of the impedance of the skin varies widely with surface area of contact, temperature, respiration, etc, even for one person.

For higher touch voltages in the order of approximately 50 V to 100 V the skin impedance decreases considerably and becomes negligible when the skin breaks down.

As regards the influence of frequency, the impedance of the skin decreases when the frequency increases.

##### 4.3 Total impedance of the human body ( $Z_T$ )

The total impedance of the human body consists of a resistive component and a capacitive component.

For touch voltages up to approximately 50 V, on account of considerable variations in the impedance of the skin  $Z_p$ , the total impedance of the human body  $Z_T$  similarly varies widely.

For higher touch voltages, the total impedance depends less and less on the impedance of the skin and after breakdown of the skin its value approaches that of the internal impedance  $Z_i$ .

As regards the influence of frequency, taking into account the frequency dependence of the skin, the total impedance of the human body is higher for direct current and decreases when the frequency increases.

##### 4.4 Initial resistance of the human body ( $R_i$ )

At the moment when the touch voltage occurs, capacitances in the human body are not charged. Therefore skin impedances  $Z_p$  are negligible and the initial resistance  $R_i$  is approximately equal to the internal impedance of the human body  $Z_i$  (see Figure 1).  $R_i$  depends mainly on the current path and to a lesser extent on the surface area of contact.

The initial resistance  $R_i$  limits the current peaks of short impulses (e.g. shocks from electric fence controllers).

## 5. Values of the total impedance of the human body ( $Z_T$ )

The values of the total body impedance given in Table I are valid for living human beings and a current path hand to hand or hand to foot for large contact areas (50 cm<sup>2</sup> to 100 cm<sup>2</sup>) and dry conditions.

At voltages up to 50 V, values measured with contact areas wetted with normal water are 10% to 25% lower than in dry conditions and conductive solutions decrease the impedance considerably down to half of the values measured in dry conditions.

At voltages higher than approximately 150 V the total body impedance depends only slightly on humidity and on the surface area of contact.

The measurements have been made on adults (males and females). The range of the total body impedance for touch voltages up to 5 000 V is presented in Figure 3, page 6, and for touch voltages up to 700 V in Figure 4, page 6.

The values of Table I and Figures 3 and 4 represent at present the best knowledge on the total body impedance for living adults. On the knowledge at present available the total body impedance for children is expected to be in the same order.

TABLE I  
Total body impedance  $Z_T$

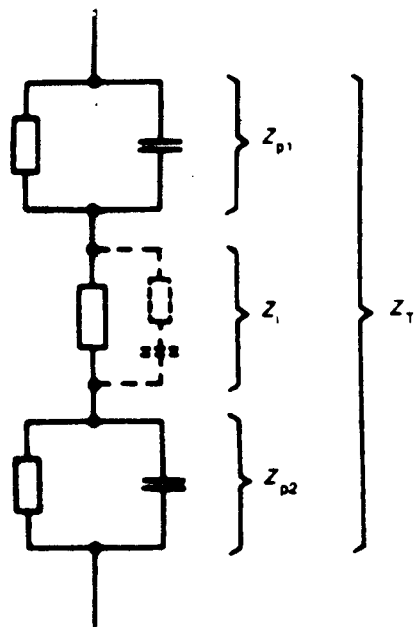
Touch voltage (V)	Values for the total body impedance( $\Omega$ ) that are not exceeded for a percentage (percentile rank) of		
	5%	50%	95%
	of the population		
25	1 750	3 250	6 100
50	1 450	2 625	4 375
75	1 250	2 200	3 500
100	1 200	1 875	3 200
125	1 125	1 625	2 875
220	1 000	1 350	2 125
700	750	1 100	1 550
1 000	700	1 050	1 500
Asymptotic value	650	750	850

Notes 1. — These values have been derived as described in Appendix A.

2. — Values for persons immersed in water are under consideration.

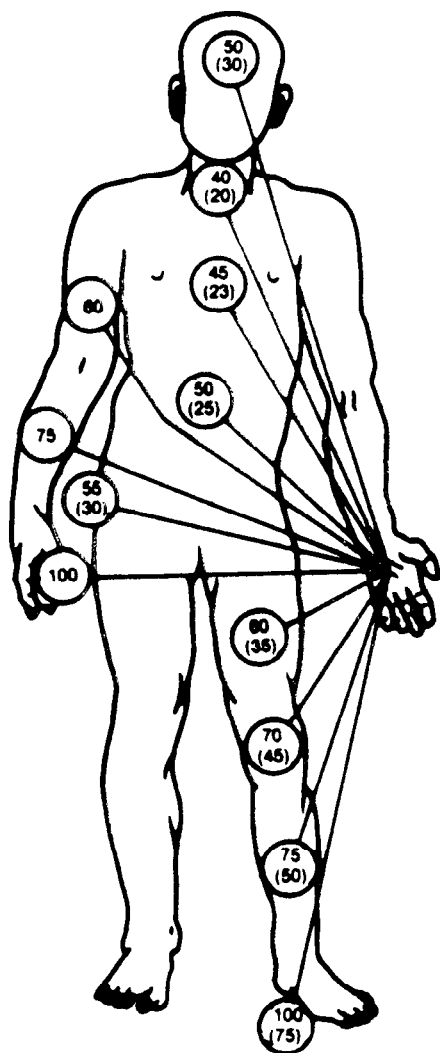
## 6. Value of the initial resistance of the human body ( $R_i$ )

The value of the initial resistance of the human body for a current path hand to hand or hand to foot and large contact areas can be taken as equal to 500  $\Omega$  for the 5% percentile rank.



$Z_i$  = internal impedance  
 $Z_{p1}, Z_{p2}$  = impedances of the skin  
 $Z_t$  = total impedance

FIG. 1. — Impedances of the human body.



The numbers indicate the percentage of the impedance of the human body for the path concerned, in relation to the path hand to hand.

The numbers not in brackets refer to the current paths from one hand to the part of the body in question. The numbers in brackets refer to current paths between two hands and the corresponding part of the body.

Notes 1. — The impedance from one hand to both feet is 75% and the impedance from both hands to both feet 50% of the impedance from hand to hand.

2. — As first approximation the percentages are also valid for the total body impedance.

FIG. 2. — Internal impedance of the human body as a function of the current path.

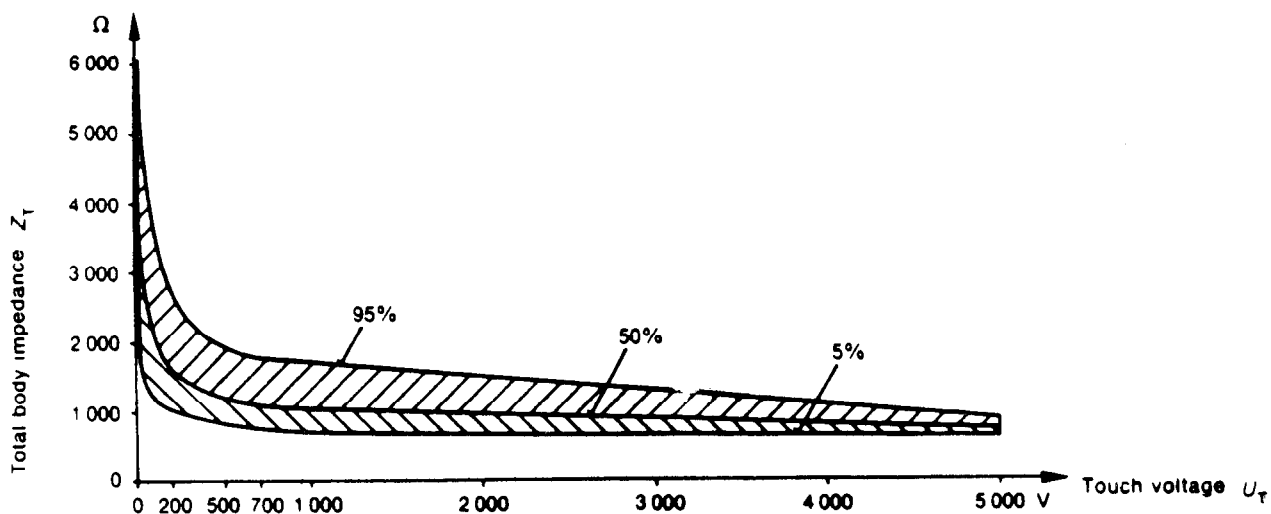


FIG. 3. — Statistical values of total body impedances valid for live human beings for the current path hand to hand or hand to foot, for touch voltages up to 5000 V.

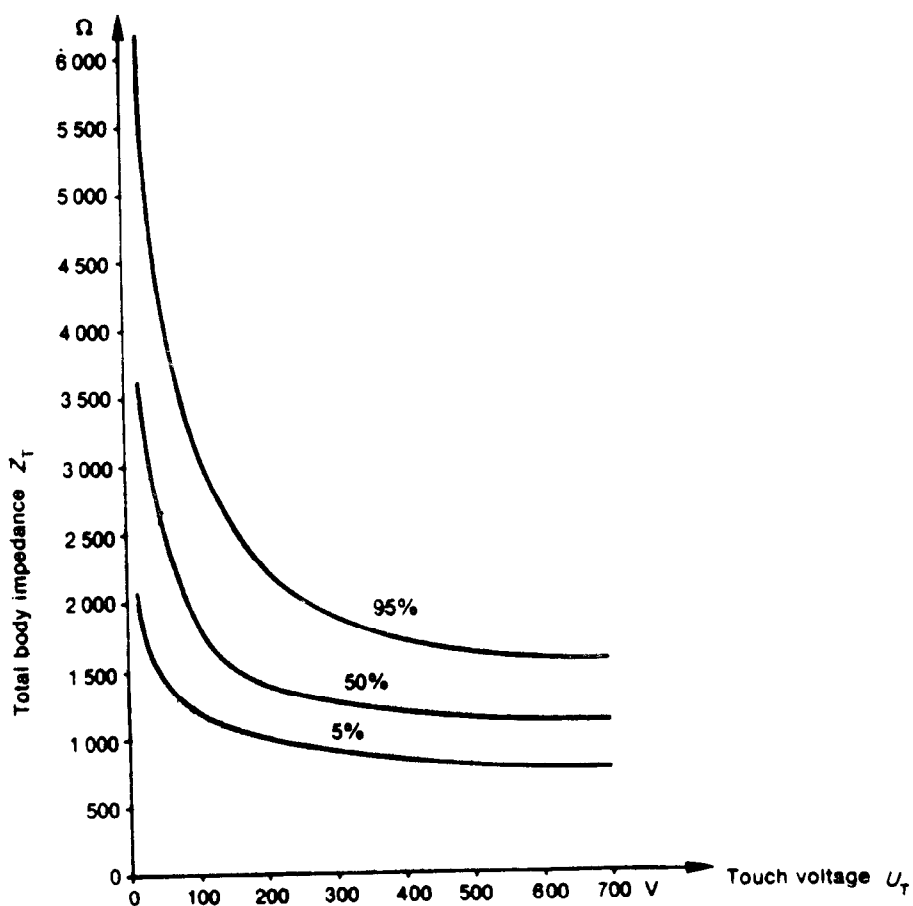


FIG. 4. — Statistical values of total body impedances valid for live human beings for the current path hand to hand or hand to foot, for touch voltages up to 700 V.

## APPENDIX A

### MEASUREMENTS MADE ON LIVING AND DEAD HUMAN BEINGS AND THE STATISTICAL ANALYSIS OF THE RESULTS

In order to obtain realistic values for the total body impedance of living human beings, the following procedure was applied:

1. Measurements were made on 50 living persons at a touch voltage of 15 V and on 100 living persons at 25 V with a current path hand to hand with large electrodes (approximately 80 cm<sup>2</sup>) in dry conditions.

The values for the total body impedances for a percentile rank of 5%, 50% and 95% were determined by two independent statistical methods which gave nearly the same results.

The measurements were made 0.1 s after applying the voltage.

2. The total body impedance of one living person was measured under the conditions of Item 1 above with touch voltages up to 150 V and in addition with shock durations up to 0.03s for touch voltages up to 200 V.
3. Measurements were made on a large number of corpses under conditions similar to Item 1 above for current paths hand to hand and hand to foot with large electrodes (approximately 90 cm<sup>2</sup>) for touch voltages of 25 V to 5 000 V in dry and wet conditions. The values for the total body impedances for a percentile rank of 5%, 50% and 95% were determined as in Item 1.

The measurements were made 3 s after applying the voltage.

4. The total body impedances measured with corpses (Item 3 above) which for touch voltages up to 220 V showed excessively high skin impedances were modified by adjusting the curves to the values measured on living persons.
5. The difference between current paths hand to hand and hand to foot proved to be negligible for practical purposes.

## CHAPTER 2: EFFECTS OF ALTERNATING CURRENT IN THE RANGE OF 15 Hz TO 100 Hz

### 1. General

This chapter is primarily based on the findings related to the effects of currents at frequencies of 50 Hz or 60 Hz which are the most common in electrical installations. The values given are, however, deemed applicable over the frequency range from 15 Hz to 100 Hz, threshold values at the limits of this range being higher than those at 50 Hz and 60 Hz.

This chapter considers principally the risk of ventricular fibrillation which is the main cause of fatal accidents in that range of frequencies.

### 2. Scope

This chapter describes the effects of alternating current passing through the human body within the frequency range 15 Hz to 100 Hz.

*Note.* — Unless otherwise specified, the current values defined hereinafter are r.m.s. values.

### 3. Definitions

#### 3.1 *Threshold of perception*

The minimum value of current which causes any sensation for the person through which it is flowing.

#### 3.2 *Threshold of let-go*

The maximum value of current at which a person holding electrodes can let go of the electrodes.

#### 3.3 *Threshold of ventricular fibrillation*

The minimum value of current which causes ventricular fibrillation.

#### 3.4 *Heart current factor*

The heart current factor relates the electric field strength in the heart for a given current path to the electric field strength in the heart for a current of equal magnitude flowing from left hand to feet.

*Note.* — In the heart, the current density is proportional to the electric field strength.

#### 3.5 *Vulnerable period*

The vulnerable period covers a comparatively small part of the cardiac cycle during which the heart fibres are in an inhomogeneous state of excitability and ventricular fibrillation occurs if they are excited by an electric current of sufficient magnitude.

*Note.* — The vulnerable period corresponds to the first part of the "T-wave" in the electrocardiogram which is approximately 10% to 20% of the cardiac cycle (see Figures 6 and 7, page 13).

#### 4. Effects of current

##### 4.1 *Threshold of perception*

The threshold of perception depends on several parameters, such as the area of the body in contact with an electrode (contact area), the conditions of contact (dry, wet, pressure, temperature), and also on physiological characteristics of the individual.

A general value of 0.5 mA, independent of time, is assumed in this report.

##### 4.2 *Threshold of let-go*

The threshold of let-go depends on several parameters, such as the contact area, the shape and size of the electrodes and also on the physiological characteristics of the individual.

A value of about 10 mA is assumed in this report.

##### 4.3 *Threshold of ventricular fibrillation*

The threshold of ventricular fibrillation depends on physiological parameters (anatomy of the body, state of cardiac function, etc) as well as on electrical parameters (duration and pathway of current flow, kind of current, etc)

With a.c. (50 Hz or 60 Hz) there is a considerable decrease of the threshold of fibrillation if the current flow is prolonged beyond one cardiac cycle. This effect results from the increase in inhomogeneity of the excitatory state of the heart due to current-induced extrasystoles.

For shock durations below 0.1 s, fibrillation may occur for current magnitudes above 500 mA, and is likely to occur for current magnitudes in the order of several amperes, only if the shock falls within the vulnerable period. For shocks of such intensities and durations longer than one cardiac cycle reversible cardiac arrest may be caused.

In adapting the results from animal experiments to human beings, a curve was constructed below which fibrillation is unlikely to occur. The high level for short durations of exposure between 10 ms and 100 ms was chosen as a descending line from 500 mA to 400 mA. On the basis of information on electrical accidents the lower level for durations longer than 1 s was chosen as a descending line from 50 mA at 1 s to 40 mA for durations longer than 3 s. Both levels were connected by a smooth curve derived from experimental results.

##### 4.4 *Other effects of current*

Ventricular fibrillation is considered to be the main cause of death by electrical shock. There is also some evidence of death due to asphyxia or cardiac arrest.

Patho-physiological effects such as muscular contractions, difficulty in breathing, rise in blood pressure, disturbances of formation and conduction of impulses in the heart including atrial fibrillation and transient cardiac arrest may occur without ventricular fibrillation. Such effects are nonlethal and usually reversible; current marks may occur.

With currents of several amperes, heavy burns resulting in serious injury and even death are likely to occur.

#### 4.5 Description of zones (see Figure 5, page 12)

TABLE II

Zones	Physiological effects
Zone 1	Usually no reaction effects.
Zone 2	Usually no harmful physiological effects.
Zone 3	Usually no organic damage to be expected. Likelihood of muscular contractions and difficulty in breathing, reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
Zone 4	In addition to the effects of Zone 3, probability of ventricular fibrillation increasing up to about 5% (curve $c_2$ ), up to about 50% (curve $c_3$ ) and above 50% beyond curve $c_3$ . Increasing with magnitude and time, pathophysiological effects such as cardiac arrest, breathing arrest and heavy burns may occur.

#### 4.6 Experience with voltages not exceeding 50 V r.m.s. a.c.

From the replies given by several countries to a questionnaire it appears that there is no conclusive evidence in any of those countries of electrical accidents occurring under usual circumstances at supply voltages not exceeding 50 V r.m.s. a.c. and caused by a current passing through the body that led to serious injury.

#### 5. Application of heart-current factor

The heart-current factor permits the calculation of currents  $I_h$  through paths other than "left hand to feet" which represent the same danger of ventricular fibrillation as that corresponding to  $I_{ref}$  "left hand to feet" given in Figure 5, page 12.

$$I_h = \frac{I_{ref}}{F}$$

where:

$I_{ref}$  is the body current for path "left hand to feet" given in Figure 5

$I_h$  is the body current for paths given in Table III

$F$  is the heart-current factor

*Note.* — The heart-current factor is to be considered as only a rough estimation of the relative danger of the various current paths with regard to ventricular fibrillation.

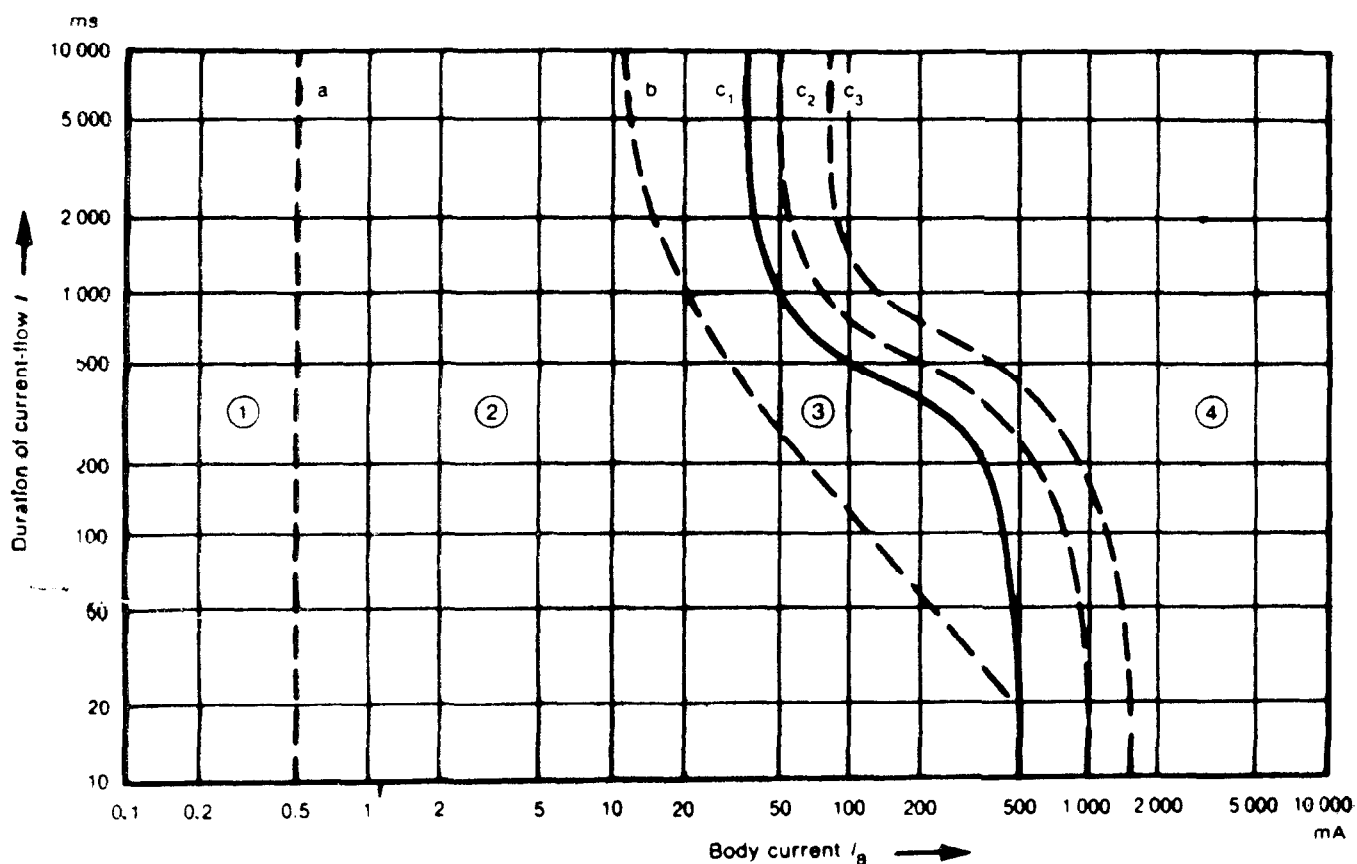
For the different current paths, the following heart-current factors are given in Table III.

**TABLE III**  
*Heart-current factor for different current paths*

Current path	Heart-current factor
Left hand to left foot, right foot or feet	1.0
Both hands to feet	1.0
Left hand to right hand	0.4
Right hand to left foot, right foot or feet	0.8
Back to right hand	0.3
Back to left hand	0.7
Chest to right hand	1.3
Chest to left hand	1.5
Seat to left hand, right hand or to both hands	0.7

For example a current of 200 mA hand to hand has the same effect as a current of 80 mA left hand to feet.

Zones	Physiological effects
Zone 1	Usually no reaction effects.
Zone 2	Usually no harmful physiological effects.
Zone 3	Usually no organic damage to be expected. Likelihood of muscular contractions and difficulty in breathing, reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
Zone 4	In addition to the effects of Zone 3, probability of ventricular fibrillation increasing up to about 5% (curve $c_2$ ), up to about 50% (curve $c_3$ ) and above 50% beyond curve $c_3$ . Increasing with magnitude and time, pathophysiological effects such as cardiac arrest, breathing arrest and heavy burns may occur.



Notes 1. — As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path "left hand to feet". For other current paths, see Clause 5 and Table III.

2. — The point 500 mA/100 ms corresponds to fibrillation probability in the order of 0.14%

FIG. 5. — Time/current zones of effects of a.c. currents ( 15 Hz to 100 Hz ) on persons.

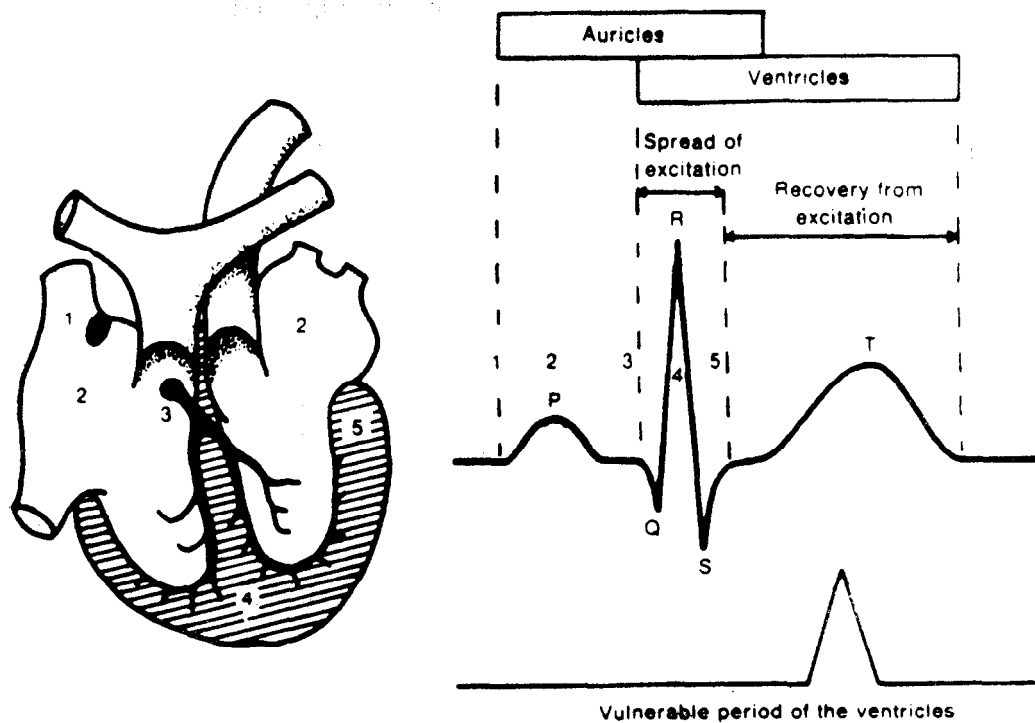


FIG. 6. — Occurrence of the vulnerable period of ventricles during the cardiac cycle.  
The numbers designate the subsequent stages of propagation of the excitation.

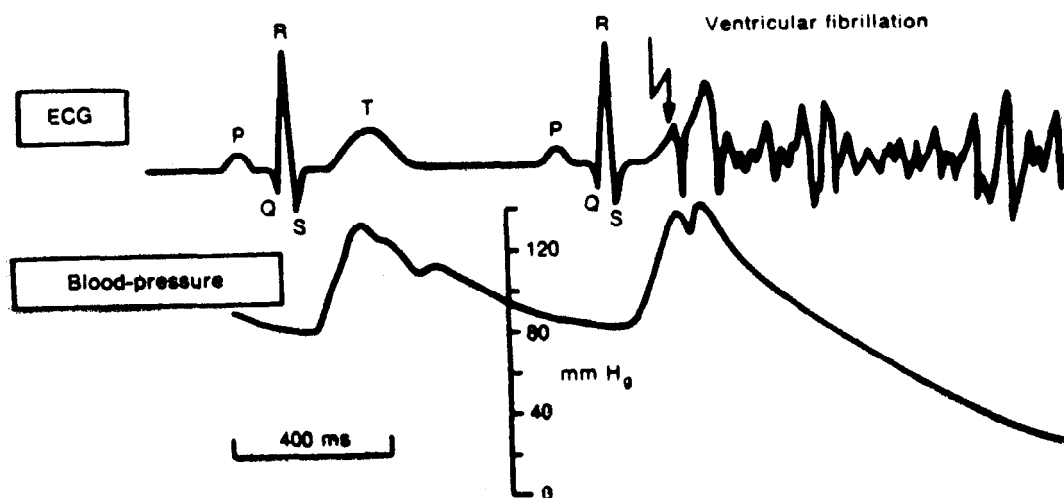


FIG. 7. — Triggering of ventricular fibrillation in the vulnerable period.  
Effects on electrocardiogram ( ECG ) and blood-pressure.

## CHAPTER 3: EFFECTS OF DIRECT CURRENT

### 1. General

Accidents with direct current are much less frequent than would be expected from the number of d.c. applications, and fatal accidents occur only under very unfavourable conditions, for example in mines. This is partly due to the fact that with direct current the let-go of parts gripped is less difficult and that for shock durations longer than the period of the cardiac cycle the threshold of ventricular fibrillation remains considerably higher than for alternating current.

The main differences between the effects of a.c. and d.c. on the human body result from the fact that excitatory actions of the current (stimulation of nerves and muscles, induction of cardiac atrial or ventricular fibrillation) are linked to the changes of the current magnitude especially when making and breaking the current. To produce the same excitatory effects the magnitude of direct current flow of constant strength is two to four times greater than that of alternating current.

### 2. Scope

This chapter describes the effects of direct current passing through the human body.

*Notes 1.* — The term “direct current” means ripple-free direct current. However, as regards fibrillation effects, the data given in this chapter are considered to be conservative for direct currents having a peak to peak ripple content not exceeding 15%.

2. — The influence of ripple is dealt with in Chapter 5.

### 3. Definitions

In addition to the definitions given in Chapter 2, the following ones apply for the purpose of this chapter.

#### 3.1 *D.C./A.C. equivalence factor (k)*

Ratio of a direct current to its equivalent r.m.s value of alternating current having the same probability of inducing ventricular fibrillation.

*Note.* — As an example for shock durations longer than the period of one cardiac cycle the equivalence factor is approximately:

$$k = \frac{I_{d.c.-fibrillation}}{I_{a.c.-fibrillation(r.m.s.)}} = \frac{300 \text{ mA}}{80 \text{ mA}} = 3.75$$

#### 3.2 *Longitudinal current*

Current flowing lengthwise through the trunk of the human body such as from hand to feet.

#### 3.3 *Transverse current*

Current flowing crosswise through the trunk of the human body such as from hand to hand.

#### 3.4 *Rising current*

Direct current through the human body for which the feet represent the positive polarity:

#### 3.5 *Falling current*

Direct current through the human body for which the feet represent the negative polarity.

#### 4. Effects of current

##### 4.1 *Threshold of perception*

The threshold of perception depends on several parameters, such as the contact area, the conditions of contact (dryness, wetness, pressure, temperature), the duration of current flow and on the physiological characteristics of the individual. Unlike a.c., only making and breaking of current is felt and no other sensation is noticed during the current flow at the level of the threshold of perception. Under conditions comparable to those applied in studies with a.c., the threshold of perception was found to be about 2 mA.

##### 4.2 *Threshold of let-go*

Unlike a.c. there is no definable threshold of let-go for d.c. for current magnitudes below approximately 300 mA. Only the making and breaking of current leads to painful and cramp-like contractions of the muscles.

Above approximately 300 mA, let-go may be impossible or only possible after several seconds or minutes of shock duration.

##### 4.3 *Threshold of ventricular fibrillation*

As described for a.c. (see Chapter 2, Sub-clause 4.3), the threshold of ventricular fibrillation induced by d.c. depends on physiological as well as on electrical parameters.

Experiments on animals as well as information derived from electrical accidents show that the threshold of fibrillation for a falling current is about twice as high as for a rising current. For a current path hand to hand ventricular fibrillation is unlikely to occur.

For shock durations longer than the cardiac cycle the threshold of fibrillation for d.c. is several times higher than for a.c. For shock durations shorter than 200 ms the threshold of fibrillation is approximately the same as for a.c., measured in r.m.s. values.

In comparison with the time/current zones for a.c. (see Figure 5, page 12) a curve has been constructed separating the zone where fibrillation becomes likely from the zone where less harmful effects are to be expected (see Figure 8, page 16). This curve applies to a longitudinal rising current. With a longitudinal falling current the curve has to be shifted to a higher current magnitude by a factor of about two.

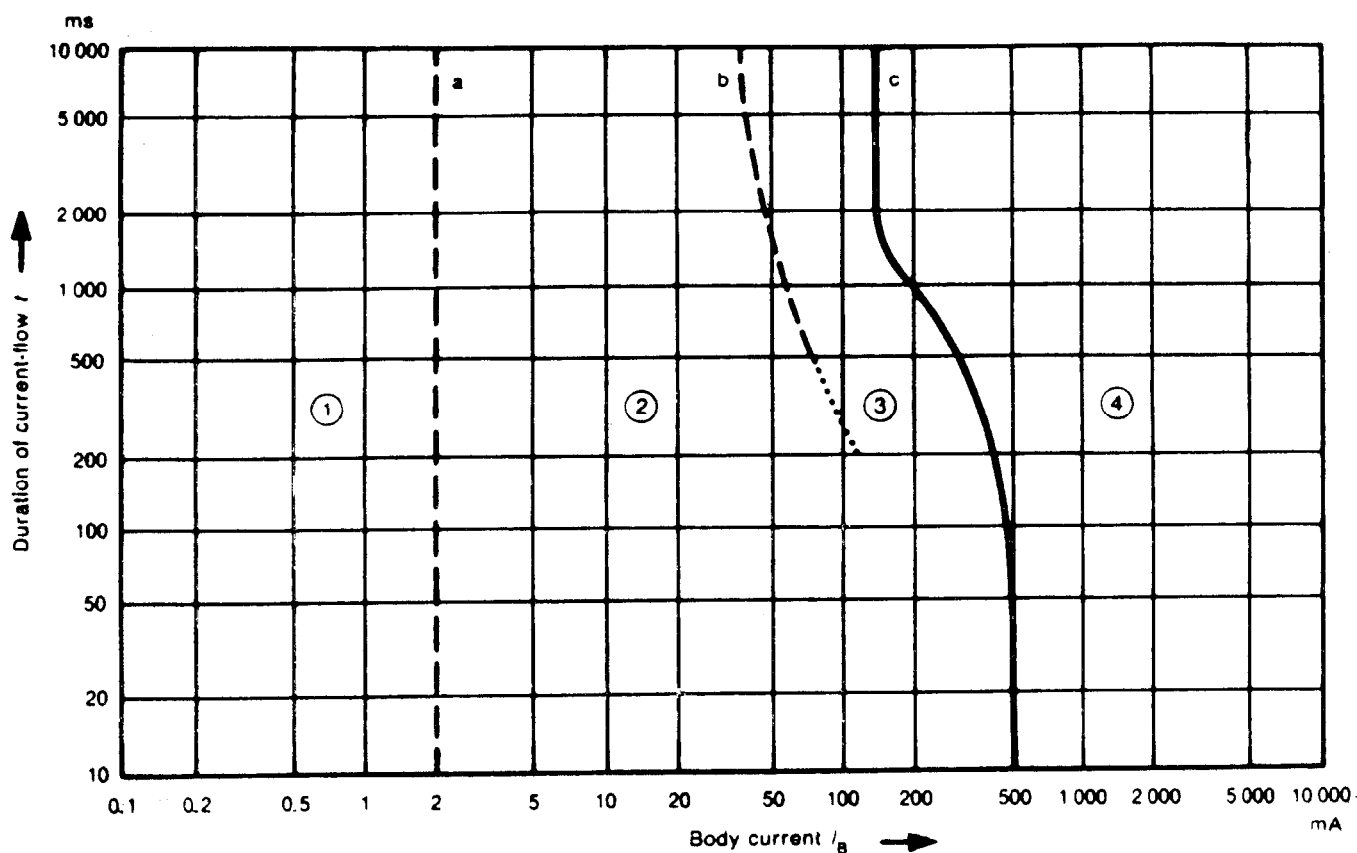
##### 4.4 *Other effects*

Below approximately 300 mA a sensation of warmth is felt in the extremities during the flow of the current.

Transverse currents up to 300 mA flowing through the human body for several minutes might, increasing with time and current, cause reversible cardiac dysrhythmias, current marks, burns, dizziness and sometimes unconsciousness. Above 300 mA unconsciousness frequently occurs.

4.5 Description of zones (see Figure 8)

Zones	Physiological effects
Zone 1	Usually no reaction effects.
Zone 2	Usually no harmful physiological effects.
Zone 3	Usually no organic damage is to be expected. Increasing with current magnitude and time, reversible disturbances of formation and conduction of impulses in the heart are likely.
Zone 4	Ventricular fibrillation likely. Increasing with current magnitude and time other pathophysiological effects, for example heavy burns, are to be expected in addition to the effects of Zone 3.



Notes 1. — As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to feet and for rising current.

2. — Boundary between Zones 2 and 3 unknown for times less than 500 ms.

FIG. 8. — Time/current zones for d.c.

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( Continued from second cover )

IEC/TC 64 in which the Indian National Committee actively participated, the Technical Committee under ETD responsible for this standard has decided to revise IS 8437 in line with the latest IEC Pub on the subject.

The test of IEC Pub 479-1 has been considered and approved by ET 20 as suitable for publication as Indian Standard, to serve as a revision of IS 8437. It has been agreed that this standard together with Part 2 corresponding to IEC 479-2 would together replace IS 8437 : 1977.

#### CROSS REFERENCES

Nil

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